IV. "A Summary of an Inquiry into the Function of Respiration at Various Altitudes on the Island and Peak of Teneriffe." By William Marcet, M.D., F.R.S. Received March 31, 1879.

On the 19th March of last year, I presented to the Royal Society a short summary of an inquiry on the function of respiration at various altitudes in the Alps. The principal result obtained was that a greater quantity of carbonic acid was formed in the body and exhaled at the higher than at the lower stations. Thus, after experimenting on a spot near the Lake of Geneva, at an altitude of 1,230 feet, and at the summit of the Breithorn, at an altitude of 13,688 feet, there was found to be an excess of 15 per cent. for the carbonic acid expired at the highest station. I had come to the conclusion that the increased formation of carbonic acid in the body at certain altitudes in the Alps appeared necessary, as a means of resisting the influence of cold which is occasionally very great in high Alpine regions.

The question which now offered itself for inquiry was whether, on rising to a considerable altitude above the sea in a warm climate, there would be, as I had found in the Alps, an increase of the carbonic acid expired. After some consideration, the Peak of Teneriffe, in north latitude 28°, was selected as the place best calculated for investigating the subject. The advantages of this site were manifold. First, a mean temperature in the day time, which proved to be not lower than 64° in the shade, could be secured at an altitude above 10,000 feet; next as the mountain rose from the sea, various stations, beginning at the seaside, might be selected; then fine weather could be relied upon in June and July, on the Island of Teneriffe; finally, the spot was situated at an accessible distance from England.

It took me three weeks to collect the necessary instruments, among which was a wooden shed, taking to pieces and made to pack in a comparatively small space. It consisted of six deal boards constructed so as to fit side by side with overlaping edges; when mounted, they formed a flat square roof. The four corners of this roof were supported by four poles held upright by tent ropes and pegs; broad strips of canvas were nailed to two opposite sides of the roof and spread out, being held in position by strings and pegs. The boards covered a square of 6 feet on each side and the sheltered area was much increased by the canvas. The shed was placed lengthways as nearly as possible in the direction of the course of the sun, and by this means we could work all day long in the shade, a necessary condition for the success of the inquiry.

My experimental baggage included two large baskets holding about 150 bottles of a capacity of rather more than 100 cub. centims. each,

and full of a titered solution of barium hydrate, in addition to which there were a number of empty bottles of the same size. The bottles holding the alkaline solution were carefully corked and the corks sealed with paraffin. I must also allude to two strong deal boards or rocking-boards, 6 feet in length and supplied with two iron sockets midway between the two ends; the sockets fitted upon an iron bar raised a few inches high on a firm wooden stand. Two square open wooden boxes were made to fasten at one end of each board respectively, and could be filled with stones or sand up to a given weight. The use of these boards will be explained in the course of the present communication.

In addition to the above apparatus I carried with me a balance and everything required for determining the moisture expired from the lungs. My experimental baggage used in the Alps was also included, together with every requisite for camping out on the Peak for about three weeks.

My Chamounix guide, Edouard Cupelin, who has accompanied me for the last ten years in the Alps, and is thoroughly used to the manipulations connected with my experiments, came out with me to Teneriffe. He not only assisted me most effectually, but also submitted himself to experiment.

We arrived at the Island of Teneriffe on the 25th of June last, and after landing at Santa Cruz, proceeded at once to Puerto de Orotava, at the foot of the Peak. Three principal stations were selected, two at different altitudes on the Peak, and one at the seaside; while from the highest station instruments could be carried to the foot of the terminal cone, and also to the summit of the Peak 12,200 feet above the sea, where I proposed making a few experiments.

We remained eleven days at the lowest station on the Peak, at an altitude of 7,090 feet, and ten days at the higher station 10,700 feet above the sea.

The characters of the stations bearing on my experiments were:—

1. The topographical position and atmospheric pressure.
2. The temperature of the air.
3. The hygrometric state of the atmosphere.

1*st. The position and atmospheric pressure.* My lowest station on the Peak, that of Guajara, was situated on a sandy plateau at the foot of Mount Guajara, known from Professor Piazzi Smyth having established an astronomical station at the summit in 1856. The mountain rose 1,800 feet above my station in the S.W., while in the opposite direction for 200 or 300 yards, there spread a patch of white sand mixed with clay, and baked by the sun. Beyond that could be seen a bank of blocks of lava tumbled over each other, which formed the edge of an upper undulating level reaching the foot of the actual Peak at a distance of two or three miles. The heat of the sun at

that station was intense, as my tent was erected in a hollow, and the sand became so hot in the afternoon that the hand could not bear being kept in contact with it.

The mean of twenty-two readings of a Fortin barometer, by Casella, compared with the observations of Professor Smyth, taken at sea near the coast of Teneriffe, in 1856, at a similar time of the year, or nearly so, gave an altitude of 7,090 feet above the sea for that station. The stations in the Alps where my former experiments had been carried out, and corresponding in altitude with my Guajara station on Teneriffe, were the Riffel (8,425 feet) and St. Bernard (8,115 feet), these however being rather over 1,000 feet higher.

The highest of my principal stations on Teneriffe was that of Alta Vista, where Mr. Piazzi Smyth also resided in 1856. This was near the summit of the Peak on a small "plateau," occurring in a break between lava streams. This station faced an easterly aspect; in the evening a cold westerly wind often blew, sweeping down from the summit and feeling exceedingly chilly. The altitude of this station according to Piazzi Smyth, is 10,702 feet. An accident to my barometer just before leaving Guajara put an end to barometrical readings, but an observation as to the temperature of boiling water at Alta Vista gave me exactly the height as determined by Professor Smyth. This altitude compares well with that of St. Theodule, 10,899 feet, one of my stations in the Alps.

The N.E. trade winds cause a belt of clouds to hover over the island; I entered this layer of fog at an altitude of 3,200 feet, and left it at 5,500 feet, its thickness amounting therefore to 2,300 feet. My stations on the Peak were of course above the clouds; on one occasion only did I see them from Alta Vista make an irruption into the wide plateau at the foot of the peak between 6,000 and 7,000 feet high, but they soon withdrew.

2*nd*, *Temperature*.—The sky was cloudless till the last day, when a few light clouds appeared overhead, and the sun being nearly vertical at noon, in July, its direct heat was very great, although the air was much less warm in the shade; on the other hand the cold was very sharp at night. While the sandy surface of the soil was so hot at two or three o'clock in the afternoon, that the hand could not bear to be pressed against it, water left outside the tent in a bucket or in plates was on several occasions found frozen next morning just before sunrise. I had no black bulb thermometer in vacuo for observing the solar radiation, but Professor Smyth found on the summit of Mount Guajara over 180° F., with such an instrument by half-past nine o'clock in the morning, and he concludes that on August 4th, the black bulb temperature in the sun must have been 212°·4, the thermometer reading in the shade being only 60°, thus leaving the enormous quantity of 152° for the effect of sunshine at

a height of 8,900 feet. (P. Smyth—"Teneriffe—an Astronomer's Experiments.")

Although my first station was 1,810 feet below that at which Piazzi Smyth's observations were made, I cannot think the direct solar heat was notably less.

I procured at Puerto a large box, and had it perforated with many holes on every side to allow of free access of air into it. This box was used as a screen for my thermometers; if I mistake not, a similar plan had been adopted by Professor Smyth. The screen was placed under my wooden shed, and thereby sheltered from the sun. While on my Alpine stations, I was working under a mean temperature of 39° at St. Theodule, and 52° and 43° at the Riffel and St. Bernard respectively, my atmospheric temperature on the Peak of Teneriffe was from 65° to 69° in the shade, and rose in the sun much higher than on the Alps; in fact I was throughout the day time exposed to a climate much warmer than at my Alpine stations; so far, therefore, my object, in going to Teneriffe, of avoiding cold at comparatively great altitudes above the sea was attained.

3*rd*, *Moisture*.—The great dryness of the air in the daytime was very remarkable, the total mean difference between the dry and wet bulb readings at Guajara (7,090 feet) being 25°·6, and at Alta Vista (10,700 feet) 19°·7; while at Puerto de Orotava, at the seaside, the difference fell to 8°·7. I was never conscious of perspiring, and my skin was always very dry, with the throat parched at times. The evaporation from the skin must have been very great so high above the sea, in such dry air and under so powerful a sun.

The inquiry may be divided into three parts: The first refers to the respiratory phenomena at the various stations while in the sitting posture. The second, to the respiratory phenomena observed while engaged upon a definite amount of muscular work. The third, to the amount of watery vapour expired sitting at my different stations. I shall beg to commence with the experiments relating to the breathing while in the *sitting posture*.

The method adopted in these experiments was precisely the same as that I had made use of in the Alps, with this very slight difference, that instead of cooling the air expired into the bag, to the temperature of the water in the aspirator, where it was treated with the solution of barium, I noted the temperature of the air in the bag immediately after filling it, and drew the air at once from the bag into the aspirator or tube, recording its temperature in the tube. In nearly every case the temperature in the tube was rather lower than in the bag, so that a contraction took place; the degree of contraction was duly taken into account in the calculations of the analysis. I also used common water instead of a solution of salt for aspiring the air for analysis into the tube.

The air from the lungs was expired into a strong india-rubber bag of a known capacity under a pressure of one inch of water. The bag used in nearly every experiment *sitting* held 39·3 litres of air under that pressure; and in the experiments made while engaged with a measured amount of muscular work, a bag holding 68·4 litres of air under the same pressure was employed.

The tube into which the expired air was drawn for analysis was supplied with the india-rubber diverticulum described in my former communication, and I made occasional use of it to take out small quantities of air and test them with a solution of barium hydrate. I thus observed that a continued agitation of five minutes sufficed for the entire combination of the carbonic acid. In every experiment the agitation was continued for six or seven minutes or longer, by the watch. The bottles, into which the fluid was drawn after agitation, were well corked, and their necks dipped into melted paraffin. Although large enough for somewhat more than the bulk of the fluid they contained, the empty space was too small for the air it held to affect the alkaline solution.

My Chamounix guide was practised in the mode of breathing into the bag, so that I could rely upon his doing this in a perfectly natural way, and without the loss of any of the air expired; he was also in the habit of counting his expirations while so engaged.

We assisted each other mutually; one of us keeping an eye on the stop-watch and the bag, while the other was breathing into it. After sitting quiet for a few minutes, the mouth was applied to the mouthpiece, and at the very beginning of the first expiration, a sign was made and the stop-watch started. When the bag was nearly full, the water in the gauge began to rise, and the instant it attained the height of one inch, the watch was stopped. The time to fill the bag was then read off, and the temperature of the air in the bag ascertained, both observations being immediately noted. Without any loss of time the air was at once aspired into the cylinder, and its temperature within the cylinder again read off by means of a thermometer run through the india-rubber stopper.

Then followed the introduction of the normal alkaline solution, the agitation and the bottling; a whole experiment took from thirty minutes to forty-five or fifty minutes. The total number of my Teneriffe experiments on respiration, including the determination of the carbonic acid expired, amounted to 157.

The Chamounix guide is a tall and very powerful man of 38 years of age; I found him to measure round the bare chest at the nipples, 3 feet 5 inches. His height, in boots with moderately thick soles, is 6 feet $0\frac{1}{4}$ inch, and he subsequently found his weight to be 89 kilog., —exactly 14 stone.

I am 50 years of age, measure 2 feet $10\frac{1}{2}$ inches round the bare

chest, have a height in boots with moderately thick soles of 5 feet $7\frac{3}{4}$ inches, and weigh 70 kilog., say 11 stone. We are both in the enjoyment of very good health.

It will be observed that we lived precisely in the same way, were exposed to the same kind of atmospheric influence, and ate the same kind of food, although from the weight of his body, the guide consumed more than I did. The amounts of carbonic acid we expired could therefore be fairly compared with one another.

The mean weight of carbonic acid expired from sixty experiments for myself, and fifty-five for the guide, both sitting, and at the same stations respectively, was in my case, 472 mgms. per minute, and in that of the guide 604 mgms., or on 100 kilos. weight of my body, I expired 674 mgms. of carbonic acid per minute, and the guide also on 100 kilos. weight, 679 mgms. Thus it was found that we both gave out at the lungs an amount of carbonic acid proportional to the weight of our body. This is an interesting, though not unexpected result, which appears to me to give much weight to the correctness of the investigation, and consequently to the reliability of the conclusions.

Another circumstance in connexion with the present work still more deserving of notice than the former, was the fact that while we were engaged raising at each step a weight of 39·5 lbs. with the feet, on rocking boards, at the rate of 45 steps per minute, as will be subsequently described, a mean amount of carbonic acid was expired by each of us respectively, again proportional to the weight of our body. In these experiments, the mean weight of carbonic acid obtained for myself from eighteen experiments, six at three different stations, was 1·011 grms. per minute, and for the guide from the same number of experiments at the same stations 1·269 grms., giving for myself for 100 kilos. of body, 1·444 grms., and for the guide for 100 kilos. of body 1·426. Nothing can be more conclusive; we again produced within our bodies as nearly as possible the same amount of carbonic acid proportionally with our weight. These figures also show that the method adopted was well calculated to give reliable results, while engaged in a definite amount of muscular exercise.

Amount of Carbonic Acid expired at the different Stations.

The mean amount of carbonic acid expired at the several stations by both of us in the sitting posture, was found, to a great extent, to be influenced in a similar way by the food taken. In both cases, with but one exception, the greatest amount of carbonic acid expired was during the first or second hour after eating, and the quantity diminished as time elapsed from the last meal taken.* The exception

* Dr. Edward Smith's ("Phil. Trans.," 1859) experiments show that a minimum amount of carbonic acid expired is obtained while fasting, beyond which continued fasting, within certain limits, produces no further reduction.

refers to the guide at Puerto, where his maximum is found to be during the third hour after a meal. The fluctuations in my case may be said to follow closely those formerly reported from my experiments in the Alps.

The subjoined table shows at a glance the variation of the mean amount of carbonic acid expired during each successive hour after food, the fifth or sixth hour being grouped together for want of a sufficient number of experiments.

Table showing the Influence of Food on the Expiration of Carbonic Acid at the various Stations (in the sitting posture).

Self sitting.

Hours after Food.	Alta Vista. CO_2 expired per minute.	Guajara. CO_2 expired per minute.	Puerto. CO_2 expired per minute.
0 to 1 hour	0·534 (3)	0·374 (1)	0·467 (3)
1 „ 2 hours	0·502 (8)	0·497 (6)	0·496 (5)
2 „ 3 „	0·472 (5)	0·486 (4)	0·498 (6)
3 „ 4 „	0·435 (4)	0·424 (6)	0·448 (4)
4 „ 6 „		0·398 (2)	0·384 (2)

Cupelin sitting.

0 to 1 hour	0·604 (5)	0·560 (2)	No experiments.
1 „ 2 hours		0·609 (5)	0·684 (5)
2 „ 3 „	0·570 (7)	0·560 (6)	0·711 (6)
3 „ 4 „	0·525 (4)	0·565 (4)	0·684 (5)
4 „ 5 „	No experiments	0·489 (4)	0·609 (2)

The figures between brackets refer to the number of experiments. One experiment, at 5.48 A.M. at Guajara, not included.

If the figures reported in this table be taken into consideration together with the corresponding results obtained in the Alps, it will appear that the maximum amount of carbonic acid is expired rather earlier after a meal on the mountains than in the plains, which would show that there is apparently a tendency to a more rapid digestion and assimilation of food in the mountains than near the sea level.

As in the case of my former investigation, I have neutralised as much as possible the influence of food on the results of the experiments, by conducting the inquiry at all times of the day between breakfast and bedtime.

Influence of Temperature on the Carbonic Acid expired.—So far, to my knowledge, the only series of observations we possess on the influence of tropical climates on the functions of the human body, are those of Dr. Rattray, Surgeon R.N., who has clearly taken great pains to investigate the subject; he concludes that:—

"The three marked tropical phenomena, viz., diminished lung

vascularity, slower respiration, and gentler breathing are closely related, and together indicate reduced lung work, the reverse for the temperate zone marking an increased function,* &c."

Dr. Rattray infers, without apparently making any actual determination of carbonic acid in the air expired, that there is a larger amount of carbon thrown out by the lungs in temperate than in tropical climates. The consideration of the mechanical action of heat, with reference to the functions of the body, had led me long ago to adopt the same views; and previous to my Teneriffe experiment, I had believed that where the heat of the sun was in excess, less heat was required to be manufactured by the body for the due performance of its functions, and, consequently, less carbonic acid was formed and given out. I am now compelled, however, to alter this view, and to conclude that more carbonic acid is formed in the body under a tropical or nearly tropical sun than under temperate latitudes.

In order to make the subject perfectly clear, I have placed, in a tabular form, the figures showing the amount of carbonic acid expired, as found by direct experiments both in my Alpine and southern stations.

Table showing comparatively the Weights of Carbonic Acid and the Volumes of Air (reduced) expired per minute by myself and guide in the Alps and at Teneriffe.

Self sitting.

Stations.	CO_2 expired.		Volume air expired per min. (reduced to 32° and seaside pressure).		Number of experiments.
	Grm.	Increase for Teneriffe. Per ct.	Litres.	Increase for Teneriffe. Per ct.	
Alta Vista	0·486	13·8	5·14	7·8	20
Breithorn and St. Theodule	0·419		4·74		23
Guajara	0·458	9·6	5·47	16·1	20
Riffel and St. Bernard	0·414		4·63		29
Seaside, Puerto	0·471	18·7	5·84	12·0	20
Lake of Geneva	0·383		5·14		37

Cupelin sitting.

Alta Vista, Guajara	0·564	Nil	6·24	5·8	37
St. Bernard	0·565		5·88		4
Puerto	0·685	17·5	7·71	23·7	18
St. Bernard	0·565		5·88		4

The figures for the weights of CO_2 expired in the Alps have undergone a correction. See foot-note, page 507.

* "Proc. Roy. Soc.," vol. xxi, 1872.

It will be observed in this table, that, in my case, when approximately equal altitudes in the Alps and on the Peak of Teneriffe are compared as to their influence on respiration, at the highest stations there is an increase of carbonic acid expired by 13·8 per cent. for Teneriffe; at the stations next in altitude, the increase is by 9·6 per cent. for Teneriffe, and at the seaside, compared with the shores of the Lake of Geneva, the enormous increase for Teneriffe of 18·7 per cent. is noted. As to my guide, I have, unfortunately, but few experiments on the carbonic acid he expires on the Alps, which only amount to four in number. They show for approximately equal altitudes no increase of carbonic acid expired on the Peak of Teneriffe; but at Puerto de Orotava I find him to give out a very large quantity of carbonic acid in excess of that he expired in the Alps, amounting to as much as 17·5 per cent. There are no determinations of the carbonic acid expired by the guide at the altitude of Geneva, to compare with those obtained at the seaside on the Island of Teneriffe, but the increase at Teneriffe is greatly beyond any result that might have been expected at the lowest northern station.

If my excess of carbonic acid expired on the Peak of Teneriffe, over the amount expired in the higher Alps amounts to 13·8 per cent., while there is no increase in the case of the guide, this is probably owing to the guide apparently perspiring much more freely than I do, and to the circumstance that his home is in the mountains, while I am accustomed to a residence at the sea level.

This fact, that an excess of carbonic acid is expired in hot climates over that given out in temperate zones, is to me so unexpected, and, indeed, so different from what might have been anticipated, that I feel bound to give every possible proof of the accuracy of my work.

An objection might be raised to the correctness of the analysis from changes occurring in the normal solution of barium from the action of the carbonic acid of the air. This was carefully guarded against; the whole contents of one small bottle were used for each analysis, thus avoiding the necessary introduction of air in opening the bottle had the stock of the alkaline solution been carried in a single large flask. The normal solution was seen to be perfectly clear when poured into the 100 cub. centim. pipette, although it had travelled all the way from London to Teneriffe, and been carried on mule-back to near the summit of the Peak. But a circumstance still more convincing of the satisfactory state of the solution of barium was derived from the examination of a bottle of this solution, which had accidentally escaped being used at Teneriffe, and was found after my return on unpacking the basket. The solution in this bottle exhibited a small number of white specks at the bottom, there were so few that on shaking the solution looked clear; on standing the specks reappeared. I subjected this fluid to a careful analysis. 25 cub. centims.

mixed with 100 cub. centims. of distilled water gave, in order to neutralize 5 cub. centims. of the oxalic acid solution, 9·00 cub. centims. as the mean of six determinations. My normal solution of barium, analysed in London before leaving for Teneriffe, had yielded 8·92 cub. centims.; the difference was only by 0·08 cub. centim. This result would give a very slight deficiency of carbonic acid, but the error might be expected to correct itself in a number of experiments.

Finally, it might be objected that, in my Alpine experiment, a loss of carbonic acid had been experienced from the india-rubber bag into which the expired air was collected. In these experiments a certain time elapsed after filling the bag previous to the air it contained being introduced into the tube; this lapse of time ranged between a few minutes and thirty-five or forty minutes, and was required to allow the air in the bag to cool down to the temperature of the water in the tube. No doubt, after a certain time, an escape of carbonic acid might be expected to take place through the substance of the india-rubber bag, but no such escape, in any appreciable degree, could have occurred during the above-mentioned period. This I determined experimentally by subjecting a sample of expired air to analysis immediately after filling the bag, and another sample of the air from the same bag some time later. The results from four analyses made at Cannes in February (1879) were as follows:—

Experiment.	CO_2 expired per minute.	Time bag was exposed to the air.	CO_2 found after waiting.	Difference per cent.
1	0·451	25 minutes	0·454	0·66 more.
2	0·411	27 „	0·407	0·97 less.
3	0·382	50 „	0·380	0·52 „
4	0·462	30 „	0·469	1·5 more.

It is, therefore, obvious that, in my experiments on the Alps, no appreciable loss of carbonic acid through the substance of the bag took place previous to the air being subjected to analysis.*

* In the whole of these experiments the air had been aspired into the tube for analysis by means either of a nearly saturated solution of common salt or of water. It had not occurred to me, at first, that the fluid adhering to the inside of the tube would have a material influence on the volumetric analysis which was to follow. I determined the mean volume of fluid thus left in the tube, from 14 experiments, to amount to 3·3 cub. centims.; an error thus crept into the analysis, which, though not interfering with the results as to the carbonic acid expired in the Alps, relatively to each other, had, however, to be corrected when these results were compared with those obtained at Teneriffe. It was calculated for every experiment separately both in the Alps and at Teneriffe, and the correction was made accordingly. This work proved very laborious, and delayed considerably the completion of this paper. There is another probable slight source of error to be noticed in the analysis con-

It is known, from Dr. Rattray's important researches, alluded to above, that the body loses weight by a change from a temperate to a tropical climate, and recovers its weight on returning into a colder latitude, the loss appearing independent of the amount of food taken. This falling off in the substance of the body, attended, as I have shown, by an increased formation and expiration of carbonic acid, must be due to increased combustion or excessive oxidation.

It is difficult to offer a theory to explain this phenomenon in our present knowledge of the action of heat on the living body. Cold we know to increase the amount of carbonic acid formed in the body, the object of which is clearly to keep up animal heat to its normal standard; it is odd indeed that an increase of external heat should exert a similar influence. I do not think it necessary to do more than allude to a tendency to looseness of the bowels I had while on the Island of Teneriffe, which I ascribe to the heat of the climate; the guide informs me there was an opposite disposition with him at Puerto, on the seaside. These minor circumstances interfered in no way with our health, which was quite good, and our work was continued nearly daily, and all day long, during our stay at Teneriffe.

The following table gives the result, in a condensed form, of the whole of my inquiry on respiration at Teneriffe, in the sitting posture. (See p. 509.)

The chronological order of my visits to the several stations was—

1. Guajara.
2. Alta Vista.
3. Foot of Cone.
4. Puerto de Orotava (seaside).

The number of experiments made sitting amount, for myself, to 65, for the guide to 55, making altogether 120, and, in each of them, a sample of air expired during from four to six minutes was analysed. The titrations were subsequently all made by myself near Geneva, in the open air, on a balcony, and in order to guard against any accidental mistake in the calculations of the analysis, they were all done by myself and an assistant conjointly.

There was but a very slight increase in the carbonic acid expired at the two highest stations beyond the amount given out at the seaside, and it bore no comparison with the excess of carbonic acid expired at a similar altitude above the sea in the Alps. The mean excess of the

nected with the Alpine experiments, though not with those of Teneriffe, and owing to the circumstance that the solution of common salt used, probably contained a small quantity of alkaline sulphate, the alkali set free by the action of the barium exerted an influence on the titration, apparently increasing the amount of carbonic acid present. Experiments made with three different samples of common salt showed me that the error may safely be limited to 3 per cent., and is certainly much less in many instances.

Table showing the Mean Results from Experiments at Teneriffe in the Sitting Posture.

Stations.	Atmospheric pressure.	Altitude.	Mean temperature during experiments.	Weight of CO_2 expired per minute.	Volume of CO_2 (reduced) expired per minute.	Volume air expired per minute, *not reduced.*	Volume air expired per minute *reduced.*	Per cent. CO_2 in air expired by volume.	Frequency of expiration per minute.	Vol. air expired per expiration, not reduced.	Number of experiments.
		Feet.	Fahr.	Grms.	Litre.	Litres.	Litres.			Litre.	
				Self.							
Foot of Cone	506 mm., 19·922 ins. (assumed).	11,745	64°	0·471	0·239	8·04	4·99	4·9	10·0	0·81	5
Alta Vista	521 mm., 20·513 ins. (Piazzi Smyth).	10,700	64·2	0·479	0·245	8·07	5·14	4·8	11·4	0·71	20
Guajara	594 mm., 23·397 ins. (self).	7,090	69·6	0·458	0·234	7·62	5·47	4·2	11·4	0·67	21
Puerto, seaside	760 mm., 29·922 ins. (taken at).	..	75·7	0·471	0·239	6·44	5·84	4·1	7·7	0·79	20
				Cupelin.							
Alta Vista	521 mm., 20·513 ins.	10,700	66·5	0·568	0·290	10·19	6·47	4·4	10·6	0·96	16
Guajara	594 mm., 23·397 ins.	7,090	69·0	0·560	0·285	8·45	6·07	4·7	10·6	0·81	21
Puerto, seaside	29·922 inches	..	76·2	0·685	0·359	8·51	7·71	4·6	7·9	1·07	18

two highest stations on Teneriffe, above the amount expired at the seaside, is only 1·2 per cent., which is so small as to be hardly worth recording. In the Alps, at altitudes somewhat corresponding with those of the Teneriffe station, but in a much colder climate, the excess of carbonic acid expired at the highest over the lowest station was 15 per cent., while, if the mean of the four high stations over the fifth or lower station be taken, it will give an excess of 8·1 per cent.

In the case of the guide, there is not only no increase of carbonic acid expired in the high stations, but we find a considerable increase at the lowest station (above the two others), where the heat felt, and consequently absorbed, was the greatest; this increase amounts to 17·8 per cent.

The mean volume of air expired, reduced to 32° and the seaside pressure, was observed in my case to fall by 14·5 per cent. from the lowest to the highest station. With the guide there is also a decrease of air expired under similar circumstances by 16·1 per cent.

I find the percentage of carbonic acid in the air expired to increase in my case from 4·1 per cent. at the lowest station to 4·9 per cent. at the highest, while with the guide the proportion of carbonic acid in the air exhaled is nearly the same at his three stations.

The frequency of my respiration undergoes a marked reduction at the seaside, though nearly the same at my three high stations; the reduction amounts to no less than 31·2 per cent. In the case of the guide, the mean number of respirations per minute is exactly the same at his two high stations, but also falls off at the seaside by 25·5 per cent.

In all these experiments air was breathed through a mouth-piece, and on that account the rate of breathing was a little slower and apparently rather deeper than if no mouth-piece had been used. The same method was pursued in every experiment, so that the results may be compared with each other with all due regard to strict accuracy.

Respiration during a Measured Amount of Muscular Exercise.

In my former communication, I related a certain number of experiments referring to the increased expiration of carbonic acid while in the act of ascending. Since then it occurred to me that an inquiry into the amount of carbonic acid expired during a well-regulated walking exercise would yield interesting results. From the difficulty of regulating exactly the degree of muscular power exerted while walking, it occurred to me that some arrangement, on the principle of a tread-wheel, was more likely to answer my purpose, and I finally adopted the tread-boards or rocking-boards described at the beginning of the present communication. While using these boards we raised a weight of 39·5 lbs. forty-five times per minute, as measured by a metronome, to a height of 5·06 inches for every step.

Before collecting the air expired, the boards were worked at the rate of forty-five steps per minute for a short time, in order to bring the body thoroughly under the conditions of the experiment.

The 68·4 litre bag connected with the water gauge was held by the hand in the proper position, and at the same time as the first expiration into the bag was commenced a preconcerted signal caused the assistant to start the time-piece. A little practice made it quite easy to step in time with the beats of the metronome, counting the number of expirations. As soon as the water gauge showed a pressure of one inch, the watch was stopped and the number of expirations immediately recorded.

The experiment was then completed as usual.

Six experiments were made by each of us at the different stations, and the results are entered in the following table:—(See p. 512.)

On considering in this table the amount of carbonic acid exhaled, it will be observed to vary but little at the different stations for both myself and the guide respectively. In my case the amount expired at 10,700 feet and seaside is nearly the same, while there is a moderate increase at Guajara, the intermediate station. In the case of the guide the amount expired at the two highest stations is much alike, and there is a moderate decrease at the lower station.

The proportion between the mean carbonic acid expired sitting and on the rocking-boards for each of us respectively at the various stations were:—

	For myself.		For the guide.
Alta Vista	1 to 2·05	.....	1 to 2·23
Guajara	1 „ 2·35	.....	1 „ 2·35
Puerto	1 „ 2·06	.....	1 „ 1·78
Mean.....	1 „ 2·15		1 „ 2·12

Consequently, the proportion of CO_2 is a little higher for both of us at the intermediate station, while the total mean in each case is as near as possible identical, and may be safely considered as the same. These figures show, moreover, that while engaged with the regulated work on the tread-board, we each of us expired nearly twice as much carbonic acid as in the sitting posture.

The mean volume of air expired per minute, reduced, is for myself considerably smaller at the highest station than at the two others; while in the case of the guide we observe a slight falling off in the volume of air expired at the middle station.

If the relation between the volume of air and weight of carbonic acid expired for each of us at all the stations be calculated, it will be found that for myself 1 grm. of carbonic acid (expired on the tread-

Table showing the Mean Results from Experiments made on the Rocking-boards.

Stations.	Atmospheric pressure.	Altitude.	Mean temperature during experiments.	Weight of CO_2 expired per minute.	Volume CO_2 reduced expired per minute.	Volume air expired per minute, not reduced.	Volume air expired per minute reduced.	Percentage CO_2 in air expired (by volume).	Frequency of respiration per minute.	Volume air expired per expiration, not reduced.
	Inches.	Feet.	Fahr.	Grms.	Litre.	Litres.	Litres.			Litre.
				Self.						
Alta Vista	20·513	10,700	61°	0·986	0·502	15·14	9·72	5·1	13·0	1·17
Guajara	23·397	7,090	74·6	1·076	0·547	17·67	12·60	4·4	12·9	1·37
Puerto.....	29·922	Seaside	75·2	0·971	0·494	13·60	12·36	4·0	11·3	1·21
				Cupelin.						
Alta Vista	20·513	10,700	61	1·270	0·647	22·06	14·27	4·5	11·5	1·92
Guajara	23·397	7,090	74·4	1·315	0·669	18·43	13·14	5·1	12·6	1·46
Puerto.....	29·922	Seaside	75·0	1·221	0·622	15·88	14·44	4·3	9·0	1·76

boards) corresponded to 1·20 litre of air, while with the guide 1 grm. of carbonic acid corresponded to 1·48 litre.

As the mean results obtained for the amount of carbonic acid expired sitting and while on the tread-boards, agrees so well with both of us respectively, I have thought it worth while to calculate the mechanical power developed by the combustion of the amount of carbon burnt while working the tread-boards, in excess of that consumed in the sitting posture. 17·92 kilos. were raised to a height of 128·5 millims., 45 times per minute.

	Per 100 kilos.
Mean carbonic acid per minute on the tread-board	1·435
„ „ sitting	0·676
Excess „ expired on the tread-boards.....	0·759 grm.

Corresponding to 103·6 kilogrammetres ($0{\cdot}1285 \times 17{\cdot}92 \times 45 = 103{\cdot}6$) of work done, or 0·00733 ($103{\cdot}6 : 0{\cdot}759 = 1 : \times$) CO_2 expired, was equal to an oxidation of 0·002 grm. carbon, capable of raising 1 kilo. to 1 metre.

From Watts' Dictionary of Chemistry (vol. iii, pp. 105 and 129) the mechanical action of one unit of heat=423·5 gramme-metres, and one gramme of carbon yields by its combustion 8080 units of heat. Therefore, 1000 grammes carbon=8080000 units of heat yielding ($8080000 \times 423{\cdot}5$) 3421880000 gramme-metres or 3421880 kilogram-metres for the mechanical action of 1 kilogramme of carbon.

The relation between the above theoretical mechanical power of burning carbon and the actual mechanical power found to be evolved in my experiments was as follows:—

$$1000 \text{ grms.} : 3421880 = 0{\cdot}002 : \times. \quad \times = 6{\cdot}84.$$

Therefore we only applied $\frac{1}{6{\cdot}84}$, or 0·147 of the power the carbon we burnt on the tread-boards (in excess of that consumed sitting) was theoretically able to exert.*

As to the percentage of the carbonic acid in the air expired, while on the tread-boards, it increases at the highest station in my case, and this increase is somewhat gradual from the lowest to the highest station. With the guide the maximum percentage is met with at the middle station.

The frequency of the respiration increased in my case from the lowest to the highest station, while with the guide it is slightly in-

* There is so little carbonic acid present in the atmosphere, especially at some altitude above the sea (M. P. Truchot, "Compt. Rend. de l'Académie," vol. lxxvii, 1873), that its presence in the air breathed has not been taken into account in this calculation.

creased at the middle station, undergoing a marked and sudden reduction at the seaside.

Water Expired from the Lungs at the Various Stations.

The third part of my paper refers to the moisture exhaled.

It was apparent at the outset that a falling off in the atmospheric pressure, from rising above the sea, would be attended with a corresponding increase of evaporation from the lungs, and a proportional cooling effect on the respiratory organs. The apparatus used for the inquiry was disposed as follows:—

A tube drawn out at both ends was loosely filled with fragments of calcic chloride; it was large enough to ensure the absorption of the whole of the vapour expired in three minutes. One end of the tube was connected with one of my large india-rubber bags, while the other end had a ring of vulcanised india-rubber fixed round, to which the mouth was applied. A delicate spring valve (by Coxeter) was fitted into the neck of the tube next the bag, and was weighed with the tube; it effectually prevented any admission of air into the tube except that given out from the lungs. Either the tube or the bag was placed in communication with a water gauge by a neck and india-rubber tubing. Every now and then the calcic chloride was tested as to its power of retaining all the moisture; this was done by connecting another similar tube with it and weighing it after breathing through them both. No mouthpiece was used in these experiments, as moisture was found to deposit on anything interposed between the mouth and tube. The air breathed was inspired through the nose only while the whole of the air expired was driven through the tube, the nose being kept closed with the thumb and index. I found no difficulty in doing this with accuracy; great care was taken to keep the saliva from flowing into the tube together with the air expired. Except in the case of a few experiments at the summit of the Peak, I alone submitted myself to this part of the inquiry. The experiments were made by series of usually three at a time, the figures given in my table are the *means* of those of the different series.

The numbers actually obtained gave, of course, the weight of the moisture evaporated from the lungs, together with that of the atmospheric humidity of the air exhaled; a correction had, therefore, to be made. I determined the atmospheric humidity by means of dry and wet bulb thermometers, and the corresponding weight of moisture in a given bulk of air was taken from Glaisher's hygrometrical tables (fifth edition).

The results from these experiments have been condensed in the following table:—

Moisture Expired less Atmospheric Humidity Inhaled.

Stations.	Barometrical pressure.	Number of experiments.	Mean correction for humidity inhaled.*	Moisture expired corrected for atmospheric humidity.	Moisture (corrected) expired per litre.
	Inches.				
		Self.			
Summit of Peak, 12,200 feet.	17·993	3	0·043	0·324	0·0339
Alta Vista, 10,700 feet.	20·513	38	0·036	0·314	0·0330
Guajara, 7,090 feet	23·397	22	0·040	0·247	No determination.
Puerto, seaside ...	22·922	36	0·105	0·183	0·0237
		Cupelin.			
Summit of Peak, 12,200 feet.	17·993	3	0·060	0·459	0·0348

It was not without some trouble that a few successful determinations of the moisture expired were obtained at the highest point of the Peak, 12,200 feet above the sea. This summit is a cup-shaped depression, about half a mile in diameter, volcanic rocks towering round it. The depth of this crater does not appear to exceed 30 or 40 feet, and there is no difficulty in walking across it in any direction. The floor of the crater consists of a light white sandy material mixed at places with crystals of sulphur, while rocks crop out here and there. There was a great difficulty in finding a spot sheltered from the sun where I could place my balance and sit down to breathe through the tube. At last some shade was obtained for the balance by means of a blanket, and we managed to creep into a narrow place between two rocks, where the sun's rays could not penetrate. The heat was intense, the sun pouring down upon the Peak from a perfectly clear sky, and everything being nearly too hot to be touched, notwithstanding the intense terrestrial radiation at that altitude. Apparently every circumstance combined to baffle my experiments; the balance would not remain in a horizontal position; a light breeze kept blowing the fine sand about, and I had constantly to remove the beam of the balance to wipe the points of suspension; then the blanket would not keep in its required position; and I had to lay down at full length on the hot sand without any shelter from the sun to get through the weighings.

* Calculated from Glaisher's Hygrometrical Tables.

The few experiments I succeeded in completing at that spot, showed an evaporation of water from the lungs above that expired at the sea-side, equal to 0·141 grm. per minute, or 43·5 per cent.

If the weight of moisture expired at the three principal stations be considered together with the *altitudes of the stations*, a certain relation will be found to exist between them; this relation is established in the following table, showing what the proportions of humidity expired would amount to if calculated with reference to the barometrical pressures. These figures are entered in the column of the following table headed *Theory*.

Water Expired.

Barometer.	Theory.	Found.	Difference.
Puerto.... 760 millims.	0·183 grm.	0·183 grm.	
Guajara... 594·4 „	0·234 „	0·247 „	5 per cent.
Alta Vista. 521·4 „	0·267 „	0·314 „	15 „

The results obtained show, therefore, that the evaporation of moisture from the lungs increases as the barometer falls. The ratio is, however, no more than approximate. I question whether a similar result would be obtained in the Alps, where the cold at certain heights must exert a considerable influence on the evaporation from the lungs and air passages.

Results from the Investigation.

The results I have obtained from my experiments on the Island of Teneriffe may be expressed as follows:—

1. The mean of the whole amount of the carbonic acid expired at the three stations (the experiments at the foot of cone not included) in the sitting posture, and determined from 60 experiments in my case and 55 in that of the guide, was proportional to the weights of our bodies respectively, and amounted to 676 mgms. per 100 kilos. for each of us.

2. The mean weight of the whole carbonic acid expired at the three stations while engaged with the same amount of measured muscular work, and determined from 18 experiments for each of us, was respectively proportional to the weights of our bodies.

3. The mean weight of carbonic acid expired by both of us (with one exception only) was highest during the first or second hour after a meal, while it diminished by degrees as time elapsed since food was taken. This agrees with my results obtained in the Alps.

4. The mean weight of carbonic acid expired by myself on the

Island of Teneriffe is greater than it had been in the Alps, and, moreover, this same result holds good for corresponding altitudes. The mean excess for all the experiments on Teneriffe in the sitting posture, amounts for myself to 14·0 per cent. It was at the seaside that the increase in my case reached the maximum, 18·7, when compared with the weight of carbonic acid expired near the Lake of Geneva. I have only four experiments to place on record made on the guide in the Alps (St. Bernard); these compared with the means of the experiments to which he subjected himself at the seaside, Teneriffe, gave for the latter station an increased expiration of carbonic acid by 17·5 per cent. There was, however, no increase for the higher stations at Teneriffe.

5. While, in the Alps, the maximum quantity of carbonic acid was expired by myself at the highest station, 13,685 feet above the sea, where the body underwent the greatest degree of cooling, especially from the low temperature of the air; on the Peak of Teneriffe, the weight of carbonic acid I expired at the various stations differed but little.

6. The weight of carbonic acid expired in a given time by myself on the Peak of Teneriffe varies but little from one station to another, although I show a tendency to give out slightly more of this gas at the two highest stations—mean altitude 11,222 feet—than at either 7,090 feet high, or the seaside. The increase for the mean of the two highest stations above the amount expired at the seaside is only 1·2 per cent. In the Alps, the excess of carbonic acid I expired at 13,685 feet, over the amount given out near the Lake of Geneva at 1,230 feet, or for a difference of altitude of 12,455 feet, amounted to 15 per cent. This result is accounted for from the temperature of the air, which was much colder in the Alps than on the Peak of Teneriffe.

In the case of the guide, a great deal more carbonic acid was expired at the seaside on the Island of Teneriffe than on the Peak, the excess amounting to 17 per cent.; while I expired about as much carbonic acid at every altitude on that Island. This occurred apparently because the guide perspired more than I did at the higher stations; moreover, I am accustomed to live at the sea level, while the guide had never been away from the Alps, and his life, in summer, is spent, in a great measure, accompanying tourists to the highest peaks and passes in the Alps; his home at Chamounix is 3,451 feet above the sea.

7. The volume of air I expired per minute reduced to 32° F. and seaside pressure decreased gradually from the seaside to an altitude of 11,745 feet, the difference for the two extreme stations amounting to 14·6 per cent. This result agrees to some extent with that obtained in the Alps, although the Alpine decrease amounted only to 5·6 per

cent. The volume of air expired in the case of the guide exhibits a similar change, amounting to 22·6 per cent., but the decrease stops at Guajara, the intermediate station. The total mean volume of air expired per minute, at every station (the foot of the cone excepted), while in a sitting posture, was for myself 5·36 litres, and for the guide 6·75 litres.

8. The percentage of carbonic acid in the air expired exhibits nearly the same changes on the Island of Teneriffe as in the Alps. At Teneriffe it rose from 4·1 per cent. at the seaside to 4·9 per cent. at 11,945 feet, while, in the Alps, the proportion had varied from 3·8 per cent. at 1,230 feet to 4·7 per cent. (St. Bernard) at 9,403 feet. If the total mean proportion of carbonic acid in the air expired, reduced, for the three stations of Alta Vista, Guajara, and Puerto be calculated, it will be found to amount, for myself, to 4·4 per cent. and for the guide to 4·6 per cent., or to be nearly the same. The mean from the eighty-nine experiments I made in the Alps, in the sitting posture, yielded 4·2 per cent. of carbonic acid expired.

9. The frequency of the expirations fell considerably in both cases at the seaside, or increased on rising above the sea, but was much the same for each of us respectively at the different stations on the Peak. The reduction at the seaside, from the mean frequency of respiration at the upper stations, amounted for myself to 31·2 per cent., and for the guide to 25·5 per cent. In the Alps there had been a somewhat gradual rise of the frequency of the respirations between the lowest and highest stations, equal in my case to 34·9 per cent.

10. While raising with the feet a weight of 39·5 lbs. to an elevation of 5·06 inches forty-five times per minute, we both expired the least amount of carbonic acid at the lowest station, and the most at the intermediate station, 7,090 feet high. The fluctuation between the various stations was much the same for each of us respectively, although the actual amount expired by each of us differed in a marked degree. The mean relation for both of us respectively, between the carbonic acid expired sitting and on the rocking-boards, was found to be the same, and a trifle over twice the weight of the carbonic acid expired sitting.

The volume of air breathed while at work was decidedly less in my case at Alta Vista than at the two lower stations, with the guide there was a falling off in the air expired at Guajara. The mean volume of air expired per minute, in all the experiments on the rocking-boards, was for myself 11·56 litres, and for the guide 13·95 litres.

The general result obtained, with reference to this subject, was that the relation between the *volumes* of air expired while sitting, and while engaged with a regulated amount of muscular work, was the same as the relation found to exist between the *weights* of carbonic acid expired under such circumstances, and moreover that these pro-

portions were practically the same for both of us. The relations are as follows:—

		Sitting.	Rocking-board.	Relations.
Self	Air expired.....	5·36 litres	11·56 litres	1 : 2·16
	Carbonic acid expired..	0·469 grm.	1·011 grms.	1 : 2·16
Cupelin	Air expired.....	6·72 litres	13·95 litres	1 : 2·07
	Carbonic acid expired	0·603 grm.	1·269 grms.	1 : 2·10

As to the *frequency of the respiration*, while at work on the rocking-boards, it was the greatest with me at the highest station, and with the guide at the intermediate station; in both cases it was the lowest at the seaside. The mean frequency amounted, in my case, to 12·4 per minute against 10·2 sitting, giving a relation of 1·22; or for 1 respiration (expiration) sitting, I took 1·22 respiration on the tread-board. With the guide, the corresponding figures were 11·0 against 9·7, and the relation 1·13; so that for 1 respiration sitting, the guide took 1·13 respiration on the tread-board. His breathing while taking muscular exercise was, therefore, relatively rather slower than mine had been under similar circumstances.

11. The results obtained from the determination of *the water expired*, or evaporated from the lungs and air-passages, show distinctly that the moisture exhaled increases as a person rises above the sea. On the Island of Teneriffe, where the temperature in the shade is comparatively high, even at great altitudes, there is a tendency to the degree of evaporation being in an inverse ratio to the atmospheric pressure.

It is very obvious that this increased evaporation as altitude increased must have caused a corresponding loss of heat, or cooling of the lungs and air-passages; I felt this very much at night, when the temperature of the air frequently fell below freezing outside my tent. Of course, no number of blankets on our beds could check that source of cold.

The amount of water evaporated from my lungs and air-passages during twelve hours of daytime, calculated from the above data, would be—

At Alta Vista	.. ..	226·1 grms.
At Guajara ..	.. ..	177·8 „
At Puerto (seaside)..	..	131·7 „

The correction to be applied from the moisture present in the air breathed increased, of course, very much at the seaside, where it formed a considerable proportion of the moisture actually present in the air expired.